



## Purification of Treated Wastewater Effluents from Residual Detergents using Activated Carbon Produced from Olive Seeds

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This study reports the preparation and characterization of activated carbon derived from pulverized olive seeds, as well as its application in the elimination of detergents from wastewater effluents. The activated carbon was produced by carbonization followed by activation. The main characteristics of the prepared activated carbon *viz.* surface area, ash content, char yield and bulk density were determined. Batch studies were conducted to determine the primary factors influencing the removal efficiency of detergents. The factors considered were the contact time of adsorption, amount of adsorbent used, pH and the concentration of detergent. The characteristics of the produced activated carbon were surface area  $546.0 \pm 5.6$  m<sup>2</sup>/g, ash content  $1.30 \pm 0.24\%$ , char yield  $23.85 \pm 0.63\%$  and bulk density  $444.60 \pm 3.25$  kg/m<sup>3</sup>. The activated carbon effectively decreased the content of detergents to below 5 mg/L, which is the permissible limit for reusing in irrigation and recharging groundwater. This study indicates that the activated carbon derived from crushed olive seeds is effective in purifying treated wastewater effluents containing residual detergents.

**Keywords:** Wastewater, Activated carbon, Detergents, Adsorption, Olive seeds.

### INTRODUCTION

The practice of wastewater reuse is of utmost importance in locations with scarce water resources like the Gaza strip in Palestine. The five wastewater treatment plants (WWTPs) in Gaza produce a total treated effluent of 70 MCM/year which is equivalent to 35% of overall yearly water demand and equals the irrigation demand in Gaza [1]. Thus, the Palestinian Water Authority (PWA) have adopted a wastewater reuse policy to utilize this considerable quantity of water for recharge to groundwater (the main source of water supply in Gaza) and for irrigation. Unfortunately, the reuse policy faced the challenge of high residual detergents in the treated effluent in most of the Gaza WWTPs compared to the Palestinian reuse standards [2]. Therefore, additional treatment is necessary to lower the concentration of residual detergents to less than 5 mg/L in order to comply with these reuse guidelines.

Detergents in municipal wastewater is originated from laundry and dish washing detergents, soaps and other types of cleaning agents. A detergent is a mixture of surfactants with

cleaning properties in dilute solutions. Linear alkyl benzene sulphonates (LAS), alkyl ethoxy sulphates (AES) and alkyl sulphates are the most typically used surfactants in detergents production [3-5]. The presence of residual detergents in treated wastewater effluents is common due to its limited decomposability and treatability in typical activated sludge WWTPs [6]. Irrigating plants with treated wastewater that still contains detergents could have harmful effects on soil chemistry as well as plants [7]. Surfactants present in detergents are of concern due to their toxicity on plants and soil organisms [8]. Laundry detergents may infiltrate to groundwater during irrigation with treated wastewater causing adverse impact on the public health and the environment [9]. The purification of treated wastewater from detergents can be achieved by adsorption process using activated carbon treatment [10].

Activated carbon is an environmental friendly adsorbent that has good adsorption properties and can be easily prepared from a wide range of raw materials [11]. Activated carbon is typically produced from charcoal or from petrol which are raw materials susceptible to exhaustion [4]. Alternatively, activated

carbon can be produced from lignocelluloses materials, a relatively low-cost and more abundant and sustainable material. Examples on lignocelluloses materials are coconuts and seed shell of palm tree [12], barley straw [13], cocoa pod husk [14], date stone [15], olive stones and olive waste cake [16-18].

Chemical activation, the most common method of activated carbon activation, is achieved by heating the carbonized activated carbon under inert gas environment after its impregnation in a chemical agent [19,20]. Carbonization consists of a thermal decomposition of raw materials at 500 °C under inert gas environment, thus eliminating non-carbon species and producing a fixed carbon mass with a rudimentary pore structure (very small and closed pores are created during this step) [21]. On the other hand, the purpose of activation is to enlarge the diameters of the small pores and to create new pores by chemical or physical means [22].

This study investigated the production and characterization of activated carbon produced from crushed olive seeds, abundantly available from olive mills waste. Moreover, this study investigated the efficiency of the produced activated carbon in the removal of residual detergents from treated wastewater to render it suitable for reuse purposes; especially for recharge to groundwater and for irrigation. This included the investigation of the adsorption kinetics and isotherm properties. This study proposes an effective and economical technique for eliminating remaining detergents from treated wastewater, thereby preserving a valuable water resource in areas facing water constraint.

## EXPERIMENTAL

**Samples collection and preparation:** The crushed olive seeds were collected from “Yafa Street Olive Mill” in the Gaza city. The samples were washed few times with distilled water to remove dust. While washing, the pulverized olive leaves and pomace that came out in the samples floated on the water and were removed until the crushed seeds were completely free of impurities. The samples were dried for 24 h at 105 °C, grinded and sieved. The particles in the range of 1 to 2 mm were collected from the sieves and stored in closed glass jars.

**Carbonization of crushed olive seeds:** The carbonization procedure adapted in this work followed the method used by Aljundi & Jarrah [16] and Demiral *et al.* [21]. In brief, the stainless steel tube reactor was filled, in each experimental run, with 100 g of crushed olive seeds and inserted in the furnace. Then the furnace was turned on to give a temperature in the range of 550 to 650 °C and in the same time, the nitrogen gas flow into the stainless- steel tube reactor was initiated. Heating continued for 15 to 20 min under continuous nitrogen flow at the rate of 400-500 mL/min. After 10 min of heating, dense smoke and tar drips (black viscous) should begin to emerge from the outlet tube, indicating active carbonization of char. The carbonized samples are then sieved and particles in the range of 0.6 to 1.0 mm were taken for further processing.

**Char yield:** A 100 g sample of the crushed olive seeds was dried for 24 h at 115 °C and used to measure the yielding of carbonization. After carbonization, the weight of the sample was determined. The char yield is the remaining weight of char

after carbonization and calculated as the difference in weight of the sample before and after carbonization.

**Activation of char:** The activation of charcoal in this study was carried out by using the microwave technique and employing KOH as a chemical agent for activation [23,24]. In this method, a domestic microwave oven (Durabrand XB2316, UK, 700 W, 2450 MHz) was used, which consists of two holes, one at the top to insert a ventilation pipe and one at the side to insert a nitrogen gas supply pipe. A gas flow meter and pressure gauge were installed on the nitrogen gas pipe; a nitrogen gas container; a Pyrex dish contained in a clay dish with a tight clay cover. In brief, 100 g of carbonized char of 0.6 to 1 mm particle size and 200 g of KOH pellets dissolved in water were put in the Pyrex dish. The Pyrex dish was put inside the clay dish that was in turn closed tightly with a clay cover and inserted in the microwave. In this work, 5 runs were performed with activation times of 5, 10, 15, 25 and 35 min to determine the most appropriate activation time to give the best activated carbon surface area. During each run, nitrogen gas was continuously pumped at the rate of 400 to 500 mL/min. At the end of each run, the carbon samples were taken out from the microwave, filtered, washed with distilled water, dried in oven at 110 °C for 24 h and stored for further experimental studies.

### Characterization of the produced activated carbon

**Surface area:** The surface area of the produced activated carbon was experimentally measured using the acetic acid procedure. The detailed procedure of this method is described in El-Hamouz *et al.* [25].

**Ash content:** The activated carbon sample was air-dried at 150 °C until it attained a constant weight. Following a 1 h heating in furnace to 650 °C, the dry sample was weighed again. The percentage of ash content was calculated by dividing the residual mass after burning by the initial mass of the sample and then multiplying the result by 100.

**Bulk density:** The standard method ASTM D 2854 was used for measuring the bulk density. A 200 mL dried activated carbon samples was placed on a vibrating machine type (Dragon LAB SK-330-Pro) with a frequency of 250 tap/min. The sample volume was weighed after 5 min of shaking. The process was carried out again and again until the recorded volume remained unchanged.

**Removal of detergent:** A detergent synthetic solution was used to study the adsorption capacity of the activated carbon. The solution was prepared by adding a specific mass of linear alkylbenzene sulfonate (LAS) to deionized water to produce different detergent concentrations in the range of 10 to 50 mg/L. From the processed effluent of the Gaza wastewater treatment plant (WWTP), real samples of wastewater were collected, containing detergents with concentrations ranging from 2.9 to 11.4 mg/L. Based on analysis measured at Bir-Zeit University laboratory in Gaza city, Table-1 shows the typical influent and effluent characteristics of the wastewater in Gaza WWTP.

**Experimental procedures:** In this work, the produced activated carbon from crushed olive seeds was tested in batch experiments for the removal of detergents from wastewater. The first set of batch experiments were performed on synthetic

TABLE-1  
GAZA CITY WASTEWATER TREATMENT  
PLANT-WASTEWATER ANALYSIS

Item	Influent	Effluent
BOD (mg/L)	358	100
COD (mg/L)	945	257
TDS (mg/L)	2118	2145
TSS (mg/L)	568	50
Detergents (mg/L)	8 to 25	2.9 to 11.4
TKN (mg/L)	63	45
EC ( $\mu$ S/cm)	3530	3600
pH	7.88	7.68

solution (containing LAS detergent) samples to investigate, under laboratory controlled conditions. A study was conducted to investigate the effect of adsorption period, adsorbent dosage, pH and detergent initial concentration. The second set of batch experiments were performed on real wastewater samples to investigate the adsorption capacity of the produced activated carbon in the removal of detergents existing in wastewater. Table-2 presents the applied experimental parameters during the mentioned investigations. It illustrates the number of runs performed in each experiment and the values of the operating parameters in each run. In each experimental run, a 100 mL Erlenmeyer flask was filled with 50 mL of the synthetic solution or real wastewater with a specified initial detergent concentration. Then, a specific weight from the produced activated carbon was added to the flask. The pH of the solution was adjusted to the required value using HCl (1 N) or NaOH (0.2 N) and the temperature was in the range of 22-25 °C in all experi-

ments. The flask was kept in agitation at 150 rpm on a shaker (Stuart Orbital Shaker, WW-51900-21, Cole-Parmer) all over the experiment time. At the end of each experimental run, the solution was filtered to separate the activated carbon and a sample was taken to measure the residual detergent in solution. Methylene blue active substances (MBAS) method, the APHA standard method-5540 C-2000, was used for this purpose [26].

## RESULTS AND DISCUSSION

**Characteristics of produced activated carbon:** The results of main characteristic of the produced activated carbon *viz.* surface area, ash content, total yield and bulk density are discussed below.

**Surface area:** The surface area of the activated carbon was measured using acetic acid procedure mentioned in materials and methods section. Seven samples of the produced activated carbon were analyzed at an optimum activation time of 20 min [24]. The average measured surface area of the produced activated carbon in this research using the acetic acid procedure was  $546.0 \pm 5.6$  m<sup>2</sup>/g as shown in Table-3. El-Hamouz *et al.* [25], Moreno-Castilla *et al.* [23] and Martinez *et al.* [27] reported a surface area of activated carbon produced from olive seeds in the range of 400-1200 m<sup>2</sup>/g, 345-1786 m<sup>2</sup>/g and 960 m<sup>2</sup>/g, respectively. The wide range of variation in the activated carbon surface area is attributed to the different methods of carbonization and activation.

**Ash content:** As shown in Table-4, the average ash content of the produced activated carbon was found to be  $1.30 \pm 0.24\%$ . It is observed that the ash content of activated carbon in this

TABLE-2  
EXPERIMENTAL PROGRAM AND SUMMARY OF OPERATING PARAMETERS FOR EACH EXPERIMENTAL RUN

Experiment (No.)	Experiment title	Number of runs	Adsorption time (h)	Adsorbent quantity (g)	Detergent conc. (mg/L)	pH
Experiments on synthetic solution with LAS detergent						
1	Effect of the adsorption Time	3	12	1	10	6.7
		3	24	1	10	6.7
		3	36	1	10	6.7
		3	48	1	10	6.7
		3	72	1	10	6.7
		3	84	1	10	6.7
2	Effect of the Adsorbent quantity	3	20	1	10	6.7
		3	20	2	10	6.7
		3	20	3	10	6.7
		3	20	4	10	6.7
3	Effect of pH	3	20	1	10	3
		3	20	1	10	5
		3	20	1	10	7
		3	20	1	10	9
		3	20	1	10	11
4	Effect of the initial detergent concentration	3	20	1	5	6.7
		3	20	1	10	6.7
		3	20	1	25	6.7
		3	20	1	50	6.7
Experiments on real wastewater						
1	Effect of the initial detergent concentration	3	60	1	2.9	6.7
		3	60	1	5.8	6.7
		3	60	1	8.2	6.7
		3	60	1	11.4	6.7
		3	60	1	14.5	6.7

TABLE-3  
SURFACE AREA OF THE ACTIVATED  
CARBON FROM OLIVE SEEDS

Sample No.	Sample weight (g)	Activated carbon surface area (m <sup>2</sup> /g)
1	1.00	545
2	1.00	549
3	1.00	537
4	1.00	550
5	1.00	545
6	1.00	554
7	1.00	542
Ash average content (Average ± STD)		546.0 ± 5.6 m <sup>2</sup> /g

TABLE-4  
ASH CONTENT IN THE ACTIVATED  
CARBON FROM OLIVE SEEDS

Sample No.	Sample weight (g)	Ash weight (g)	Ash content (%)
1	1.32	0.021	1.59
2	1.21	0.012	0.99
3	1.10	0.015	1.36
4	1.29	0.018	1.41
5	1.18	0.013	1.13
Ash average content (Average ± STD)		1.30 ± 0.24	

research is low compared to the other reported work [25] where the ash content in their study was ≤ 6%; and 7.3% in the study of Moreno-Castilla *et al.* [23] and 3% in the commercial activated carbon produced from coconut shells by Winfield Industry. The low ash content in this work is attributed to the low content of residual minerals in the olive seeds [28]. However, the low ash content is considered as a good characteristic of activated carbon. High ash content is undesirable since it reduces the mechanical strength of carbon leading to the reduction of activated carbon adsorption capacity [29].

**Char yield:** Five activated carbon samples were dried for 24 h at 115 °C (100 g each after drying) then was carbonized. The char yield was determined as the remaining weight after carbonization. As presented in Table-5, the average char yield of produced activated carbon was found to be 23.85 ± 0.63%. The achieved value of the char yield in this work indicates the good quality of the produced activated carbon.

TABLE-5  
CHAR YIELD OF THE ACTIVATED  
CARBON FROM OLIVE SEEDS

Sample No.	Sample weight before carbonization (g)	Sample weight after carbonization (g) char yield	Char yield (%)
1	100	23.83	23.83
2	100	24.09	24.09
3	100	23.72	23.72
4	100	22.94	22.94
5	100	24.67	24.67
Average char yield (Avg ± STD)		23.85 ± 0.63 g	23.85 ± 0.63%

**Bulk density:** The average measured bulk density of the produced activated carbon was 444.60 ± 3.25 kg/m<sup>3</sup> as shown in Table-6. This result is close to the values measured by others such as Moreno-Castilla *et al.* [23] and El-Hamouz *et al.* [25]

TABLE-6  
BULK DENSITY OF THE ACTIVATED  
CARBON FROM OLIVE SEEDS

Sample No.	Sample weight (g)	Volume (mL)	Bulk density (kg/m <sup>3</sup> )
1	88.5	200	442.5
2	89.4	200	447.0
3	88.9	200	444.5
4	88.1	200	440.5
5	89.7	200	448.5
Ash average content (Average ± STD)			444.60 ± 3.25 kg/m <sup>3</sup>

who measured the bulk density of activated carbon produced from olive seeds as 450 and 480 kg/m<sup>3</sup>, respectively.

**Removal of detergents:** The adsorption capacity of the produce activated carbon was analyzed first for the removal of detergents from a synthetic solution prepared by dissolving linear alkylbenzene sulfonate (LAS), a well-known detergent, in deionized water. The main investigated factors affecting the activated carbon adsorption capacity were adsorption time (T<sub>a</sub>), adsorbent dose (D<sub>AC</sub>), pH and the initial concentration of detergent in solution (C<sub>i</sub>). Moreover, the best fitting adsorption isotherm for the removal of LAS detergent was also determined.

**Effect of adsorption time (T<sub>a</sub>):** The effect of T<sub>a</sub> on the removal of LAS detergent from aqueous solution was examined by batch experiments using 100 mL Erlenmeyer flasks. Seven flasks were used in each of the performed three experimental runs. Each flask was assigned one of the following adsorption times *viz.* 12, 24, 36, 48, 50, 62 and 84 h. Each flask contained 1 g activated carbon and a detergent solution of 50 mL with an initial detergent concentration of 10 mg LAS/L. The initial pH of the solution was adjusted at an initial pH of 6.7 and kept at room temperature in the range of 22-25 °C. At the end of the assigned adsorption time, a sample of the solution was taken from each flask and analyzed for residual LAS detergents and the percent removal was calculated. Fig. 1 illustrates the effect of T<sub>a</sub> on the percent removal of LAS detergent based on the performed experiments. As can be seen in Fig. 1, when T<sub>a</sub> increased and recovery% increased as well. For example, at T<sub>a</sub> of 24 h and 84 h, recovery% was 39% and 78%, respectively. It was also found that the removal rate (R/T<sub>a</sub>) was fast within the first 24 h (*i.e.* 39% in 24 h, 1.62% per h) compared to the second and third hour and the last 12 h where the removal rates were 18% in 24 h (0.75% per h), 17% in 24 h (0.71% per h) and 3% in the last 12 h (0.25% per h), respectively.

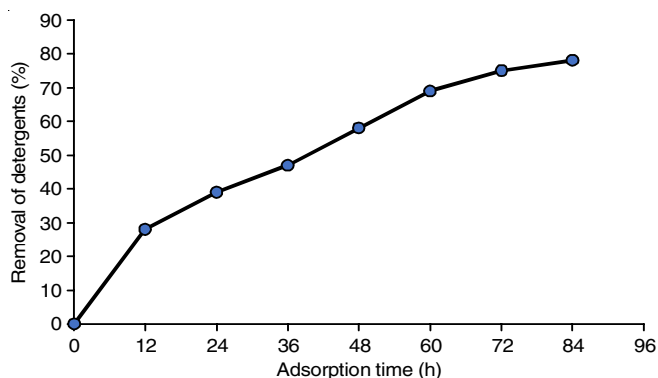


Fig. 1. Effect of adsorption time on the removal of LAS detergent

**Effect of adsorbent dose ( $D_{AC}$ ):** The effect of adsorbent dosage ( $D_{AC}$ ) on the removal of LAS detergent from the aqueous solution was investigated by batch experiments using four Erlenmeyer flasks containing 1, 2, 3 and 4 g in the 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> flasks, respectively. The volume of detergent solution was 50 mL in each flask and the initial detergent concentration was 10 mg LAS/L. The optimum parameters were adsorption time ( $T_a$ ) was taken as 20 h, the initial pH was adjusted at 6.7 and the temperature was in the range of 22 to 25 °C. As observed from Fig. 2, recovery% increased with the increase of adsorbent dosage ( $D_{AC}$ ). The increase in recovery% with the increase of  $D_{AC}$  is attributed to the increase in the surface area of the activated carbon available for detergents to get adsorbed. Moreover, Fig. 2 showed that although the percentage of adsorption increased, the amount of detergent adsorbed per unit mass of activated carbon (mg/g) decreased as  $D_{AC}$  was increased. For example, the amount adsorbed per unit mass was 3.6 mg/g and 1.9 mg/g when the adsorbent dose was 1 g activated carbon and 4 g activated carbon, respectively. This phenomenon is attributed to the unsaturation of the adsorption sites through the adsorption process [30].

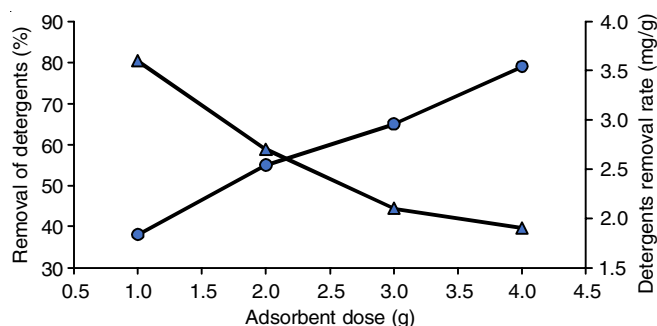


Fig. 2. Effect of adsorbent dosage on the removal of LAS detergent

**Effect of pH:** The effect of pH on the removal of LAS detergent from an aqueous solution was investigated in batch experiments using 5 Erlenmeyer flasks. The pH value was 3, 5, 7, 9 and 11 of the 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> flasks, respectively. The volume of detergent solution was 50 mL in each flask and  $C_i$  was 10 mg LAS/L,  $D_{AC}$  was 1 g,  $T_a$  was 20 h and the temperature was in the range of 22 to 25 °C.

As observed from Fig. 3, recovery% decreased rapidly from 45% to 30% when the pH was increased from 3 to 5. On the other hand, no significant decrease occurred in the pH range of 5 to 9 as recovery% decreased from 32% to 31% only. For the pH range of 9 to 11, recovery% decreased from 31% to 26%. The decrease of adsorption at low pH (3 to 5) and high pH (9 to 11) is attributed to the increase of  $H^+$  and  $OH^-$  ions, which are adsorbed quite strongly to the activated carbon compared to other ions available in the solute like LAS detergent ions, in addition water solubility is expected to increase with increasing polarity, this leads to the decrease in adsorption as polarity increases [31]. Since the wastewater has a pH between 4.5 and 8.5, it can be concluded, based on the results presented in Fig. 3, that the effect of pH on detergent removal from wastewater is insignificant.

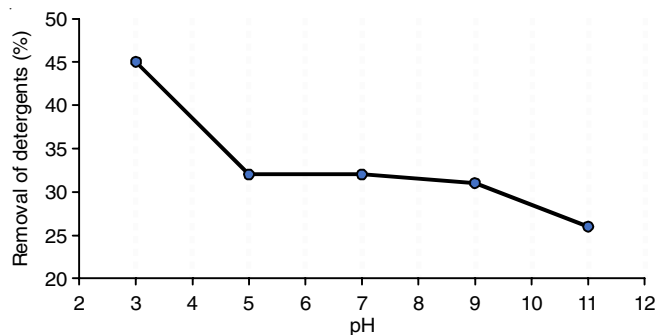


Fig. 3. Effect of pH on the removal of LAS detergent

**Effect of detergent initial concentration ( $C_i$ ):** The effect of  $C_i$  on recovery% from an aqueous solution was investigated by batch experiments using 6 Erlenmeyer flasks. The values of  $C_i$  were 5, 10, 25, 35, 45 and 50 in the 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> flasks, respectively. The volume of the detergent solution was 50 mL in each flask having  $D_{AC}$  1 g,  $T_a$  2.5 and left for 5 days. The initial pH was adjusted at 6.7 and the temperature was in the range of 22 to 25 °C.

As observed from Fig. 4,  $C_i$  has no significant effect on the recovery% in the range of 5 to 20 mg/L, as in this  $C_i$  range recovery% decreased from 94% to 93% and from 99% to 97.5% for  $T_a$  values of 2.5 and 5 days, respectively. However, recovery% decreased from 93% to 72% (for  $T_a = 2.5$  days) and from 97.5% to 77% (for  $T_a = 5$  days) when  $C_i$  increased from 20 to 50 mg/L, indicating the significant effect of  $C_i$  on recovery% in this initial detergent concentration range. This phenomenon is attributed to the ratio between the number of detergent molecules and the available adsorption sites on the activated carbon molecules. At low  $C_i$ , the number of detergent molecules is low and can be comfortably accommodated on the available adsorption sites of the activated carbon molecules, thus, recovery% becomes independent on  $C_i$ . However, at high  $C_i$  values, the available adsorption sites become fewer and hence R becomes dependent on  $C_i$ .

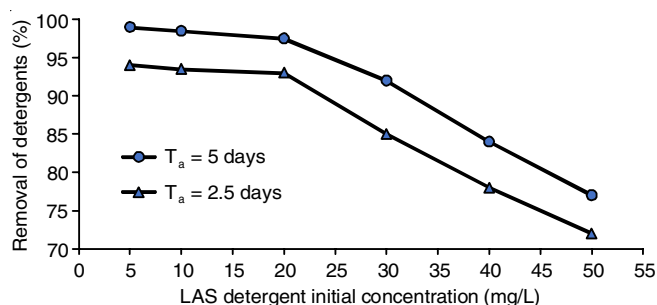


Fig. 4. Effect of LAS detergent initial concentration on the removal percent

Fig. 4 indicates that the effect of  $C_i$  on detergent removal from wastewater is negligible, as the treated wastewater usually contains residual detergent concentrations ranging from 5 to 15 mg/L. It can also be concluded that the produced activated carbon from olive seeds has a high efficiency in the removal of LAS detergent (recovery% in the range of 97-99% and 93-94%, for  $T_a$  of 2.5 and 5 days, respectively).

**Adsorption isotherm:** The obtained data from the aforementioned studies were used to investigate the most suitable adsorption isotherm (Freundlich and Langmuir) for the adsorption of LAS detergent on activated carbon derived from olive seeds. It was found that Freundlich isotherm is the best representing isotherm ( $R^2 = 0.91$ ) as shown in Fig. 5.

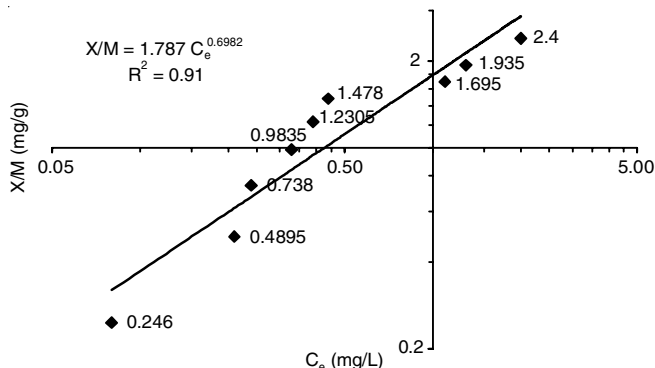


Fig. 5. Freundlich isotherm for LAS adsorption on *activated carbon* produced from olive seeds

The regression equation of the Freundlich isotherm was found to be:

$$\frac{X}{M} = k_f C_e^{1/n} = 1787 C_e^{0.682}$$

where X: Mass of detergent adsorbed and equal to  $(C_i - C_e) \times V$ ; M: Mass of the adsorbent (activated carbon) (g);  $C_i$ : Initial detergent concentration (mg/L);  $C_e$ : Equilibrium (final) concentration (mg/L); V: volume of the detergent solution in the flask or bottle (L);  $k_f$ : Freundlich capacity factor; and  $1/n$ : Freundlich intensity parameter.

The values of  $k_f$  and  $1/n$  according to the Freundlich regression equation were 1.787 and 0.682, respectively. The determination of the Freundlich isotherm as the best representing model helps in understanding the behaviour of the activated carbon produced from olive seeds in the removal of detergents from real wastewater.

**Removal of detergents from real wastewater:** The waste water samples from the effluent of Gaza WWTP was collected and analyzed for detergent concentration along with other parameters such as BOD, COD and TKN (Table-1). The detergents concentration was in the range of 2.9 to 14.5 mg/L with an average of  $10.5 \pm 4.1$  mg/L. These concentrations are above 5 mg/L, the maximum allowable detergents concentration ( $C_{max}$ ) in treated wastewater according to the Palestinian wastewater reuse standards [2]. Therefore, it is necessary to treat the effluent of Gaza WWTP in order to decrease the content of detergents. For this study, olive seeds are utilized to manufacture activated carbon.

The efficiency of prepared activated carbon in the removal of detergents from real wastewater was investigated by batch experiments using 5 Erlenmeyer flasks. The values of  $C_i$  were 2.9, 5.8, 8.2, 11.4 and 14.5 mg/L in the 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> and the 5<sup>th</sup> flasks, respectively. The 50 mL wastewater sample in each flask contained 1 g of adsorbent and the experiments were conducted at room temperature in the range of 20 to 25 °C. The

value of adsorption time ( $T_a$ ) was selected as 2.5 days based on the experimental results performed on the LAS synthetic detergent solution. From Fig. 4, at 2.5 days, the recovery% was found to be in the range of 93-94%. These recovery% values were expected to reduce the concentration of detergents in the range of 2.9-14.5 mg/L to the value of  $C_{max}$  or less.

Fig. 6 presents recovery% and the final concentration of detergents ( $C_e$ ) at the  $C_i$  range of 2.9 to 14.5 mg/L. As observed from Fig. 6, the recovery% was 93.5% at 2.5 days and  $C_i$  of 10 mg/L, for LAS detergent synthetic solution, while recovery% was 89.3% at the same adsorption time and  $C_i$  for real wastewater, which indicates that the produced activated carbon from olive seeds is capable of effectively removing detergents from treated wastewater to the acceptable wastewater reuse limits (*i.e.*  $C_{max}$ ). It was also observed that recovery% values for removing detergents from real wastewater is slightly lower than that for LAS detergents synthetic solution. This difference is attributed to the competition between detergents with other substances existing in the real wastewater on the adsorption sites of the activated carbon. The most important substances are organic matter (BOD and/or COD) and nitrogen compounds (TKN). The slight reduction of BOD<sub>5</sub> (10%) and TKN (7%) explains the insignificant effect of these substances (as adsorption competitors) on the removal efficiency of detergents from real wastewater by the produced activated carbon.

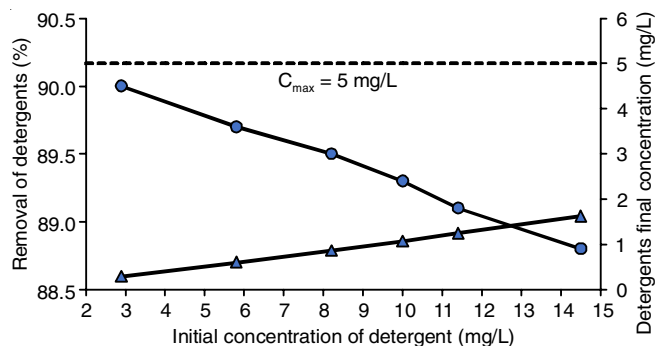


Fig. 6. Detergent removal from real wastewater samples using activated carbon produced from olive seeds

## Conclusion

Crushed olive seeds were used to prepare activated carbon, which was then used to remove detergents from the wastewater treatment plants (WWTPs). From the experiments results on the synthetic detergent solution, the removal% (R) of detergents by activated carbon was directly proportional to the adsorption time ( $T_a$ ) and the adsorbent dose ( $D_{AC}$ ). The initial detergent concentration ( $C_i$ ) has insignificant effect on the detergent removal in the range of 5 to 20 mg/L while it was directly proportional in the range of 20 to 50 mg/L. The pH has insignificant effect on the detergent removal percent in the range of 5 to 9 mg/L while it was inversely proportional in the ranges of 3 to 5 and 9 to 11. The experimental adsorption data of removing detergents from LAS synthetic solution was best fitted by Freundlich isotherm ( $R^2 = 0.91$ ). The activated carbon was capable to reduce the concentration of detergents in real wastewater from 14.5 mg/L to 2.61 mg/L, which is less than  $C_{max}$  (5

mg/L), at adsorption time ( $T_a$ ) of 2.5 days having a dosage of 1 g at pH of 6.7. This makes it possible to reuse the treated wastewater in a safe manner, either for the goal of recharging groundwater or for agricultural reasons.

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#### CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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